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ABSTRACT

While native and non-native English-speakers may approach scientific English differently, the same features cause difficulty for both groups. The difficulties generally occur more with grammar and the complex relationships between terms than with vocabularly, and may be classified in seven categories: interlocking definitions, technical taxonomies, special expressions, lexical density, syntactic ambiguity, grammatical metaphor, and semantic discontinuity. These features are closely related and tend to cluster together as characteristics of scientific discourse. They are not arbitrary, but have evolved to meet the needs of scientific method, argument, and theory. As learners master these features, they are also mastering scientific concepts and principles. The best tool available for helping students understand scientific English is functional grammar, which enables analysis of any passage in relation to its context in the discourse. (MSE)

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SOME GRAMMATICAL PROBLEMS IN SCIENTIFIC ENGLISH

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SOME GRAMMATICAL PROBLEMS IN SCIENTIFIC ENGLISH

M.A.K. Halliday

In any typical group of science students there will be some who find themselves in difficulty -- who find the disciplines of physics, or biology, or mathematics forbidding and obscure. To such students, these subjects appear decidedly unfriendly. When their teacher tries to diagnose the problems the students are having, it is usually not long before the discussion begins to focus on language. Scientific texts are found to be difficult to read; and this is said to be because they are written in 'scientific language', a 'jargon' which has the effect of making the learner feel excluded and alienated from the subject-matter.

This experience is not confined to those who are studying their science in English. It often happens in other languages also that scientific forms are difficult to understand. But here I shall be concentrating on English; and it is important to stress that it is not only ESL students who find problems with scientific English -- so also do many for whom English is the mother tongue. My impression is that, while these two groups -- those for whom English is mother tongue and those for whom it is second language -- may respond to scientific English in different ways, it is largely the same features that cause difficulties to both. For example, a pile-up of nouns as in form recognition laterality patterns, or glass crack growth rate, is hard to understand both for ESL and for EL1 students of science. The two groups may use different strategies for decoding these structures; but decoding strategies vary according to other factors also, for example the age of the learner. In so far as 'scientific English' presents special problems of its own, distinct from those of other varieties of English, the problems seem to be much the same for everybody.

In any case, in today's multilingual cities such as Birmingham, Toronto or Sydney, there is no clear line between first and second language groups of learners. A typical secondary level science class may include monolingual English speakers at one end, students who have had almost no experience of English at the other end, with the remainder spread out all the way along the continuum in between. In this situation the teacher is forced to think of the problem in terms which apply to all. But this perspective is also relevant to countries such as those of South and Southeast Asia, where the students will have been taught using a variety of different languages as their medium of instruction.

Once their attention has been directed on to the language, science teachers usually think of the difficulties first in lexical terms: that is,

as difficulties of vocabulary. This is what is implied by the term 'jargon', which means a battery of difficult technical terms. The word 'jargon' often carries a further implication, namely that such terms are unnecessary and the same meaning could have been conveyed without them, in the everyday language of ordinary commonsense. And this is, in fact, one view of scientific language: some people think that it is an unnecessary, more or less ritualistic way of writing, and that science -- scientific concepts and scientific reasoning -- could just as well be expressed in everyday, non-technical terms. They refer to this other kind of language as 'plain English', 'simple words' and the like.

We could contrast this view with the opposite opinion, which is that science is totally dependent on scientific language: that you cannot separate science from how it is written, or rewrite scientific discourse in any other way. According to this view, 'learning science' is the same thing as learning the language of science. If the language is difficult to understand, this is not some additional factor caused by the words that are chosen, but a difficulty that is inherent in the nature of science itself. It is the subject-matter that is the source of the problem.

Usually when sensible people can hold such opposite points of view, the reality lies somewhere in between; and this is certainly the case in this instance. It would not be possible to represent scientific knowledge entirely in commonsense wordings; technical terms are not simply fancy equivalents for ordinary words, and the conceptual structures and reasoning processes of physics and biology are highly complex and often far removed, by many levels of abstraction, from everyday experience. Hence the language in which they are constructed is bound to be difficult to follow. At the same time, it is often made more difficult than it need be; the forms of scientific discourse can take over, imposing their own martial law, so that writers get locked in to patterns of writing that are unnecessarily complicated and express themselves in highly technical wording even in contexts where there is no motive for it. This is the point where we can justifiably talk about 'scientific jargon': where the writer is following a fashion by which he seeks (unconsciously, in all likelihood) to give extra value to his discourse by marking it off as the discourse of an intellectual elite.

It is important to arrive at a balanced view on this question, because we not only need to identify what the problematic features of scientific English are; we also need to try and explain them -- to show what functions

these things have in the discourse as a whole, and why they have evolved as part of the language of science. This will help us to know whether, in any particular passage, the features that made it difficult to understand were motivated or not -- in other words, whether there is some good reason why the text has been written the way it is. Might it be precisely where the complexity is not motivated -- where there was no reason for the writer to have adopted that particular wording at that stage in the argument -- that the students are finding difficulties? It will take careful, well-informed classroom research to enable us to answer this last question; but we can suggest some explanations, of a general kind, for why these problematic features are found in scientific writing. The language of science, however much it may become a matter of convention, or a way of establishing the writer's own prestige and authority, is not, in origin, an arbitrary code.

But in order to understand why scientific writing became difficult in certain ways, we shall need to get rid of our obsession with words. The difficulty lies more with the grammar than with the vocabulary. In the last resort, of course, we cannot separate these from each other; it is the total effect of the wording -- words and structures -- that the reader is responding to, and technical terms are part of this overall effect. Neverthelsss technical terms are not, in themselves, difficult to master; and students are not particularly dismayed by them. It is usually the teacher who puts technical terms in the centre of the picture, because vocabulary is much more obvious, and easier to talk about, than grammar. But the generalizations we have to make, in order to help students cope with scientific writing, are mainly generalizations about its grammar. The problems with technical terminology usually arise not from the technical terms themselves but from the complex relationships they have with one another. Technical terms cannot be defined in isolation; each one has to be understood as part of a larger framework, and each one is defined by reference to all the others.

I shall suggest seven headings which can be used for illustrating and discussing the difficulties that are characteristic of scientific English:

(1) interlocking definitions
(2) technical taxonomies
(3) special expressions
(4) lexical density
(5) syntactic ambiguity
(6) grammatical metaphor
(7) semantic discontinuity

This should not be taken as a definitive listing of categories; all these features could be organized in different ways, or subdivided further, and more could certainly be added. These are simply the headings that I have found useful as a framework for working on the problem. In what follows, I have drawn on various sources, but particularly on the work of my colleagues in Sydney: Charles Taylor's study of the language of high school textbooks, with special reference to the problems of second language learners; Martin & Rothery's discussion of writing in primary schools; Wignell, Martin & Eggins' analysis of geography textbooks at junior secondary level; and Louise Ravelli's treatment of grammatical metaphor. My own analysis of scientific texts, reported on in a lecture series at the National University of Singapore, included material from four different points of origin: (i) secondary and upper primary science and mathematics textbooks from Australia, (ii) science lectures recorded at the University of Birmingham in England, (iii) writings from the Scientific American, and (iv) for a historical survey, works by Chaucer, Newton, Priestley, Dalton, Darwin and Clerk Maxwell. I found it necessary to undertake this kind of historical study in order to investigate how, and especially why, the features that were causing such problems of understanding today had themselves originally evolved.[1]

(1) Interlocking definitions. Here is an example of how a series of definitions is presented to children in upper primary school:[2]

> A circle is a plane curve with the special property that every point on it is at the same distance from a particular point called the centre. This distance is called the radius of the circle. The diameter of the circle is twice the radius. The length of the circle is called its circumference.

Here circle, centre, radius, diameter and circumference all figure in a series of interlocking definitions. Within this set, circle, centre and radius are mutually defining: they are all used to define each other, through the intermediary of two other terms which are assumed to be already known, namely distance and plane curve. The remaining terms, diameter and circumference, are then defined each by reference to one of the first three; and here two other terms are assumed to be known and mastered, namely length and twice. The pattern of definitions is as in Figure 1:

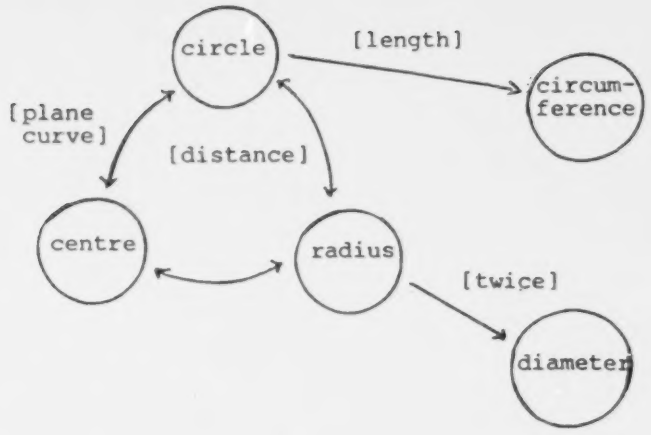

Figure 1. Interlocking definitions of five technical terms

Now, there are certain difficulties here which are specific to this example: the notions of 'plane curve', of 'every point on a curve', and of 'the length of a circle'. Likewise, any example chosen would probably present special problems of its own. But at the same time the overall semantic structure is strikingly complex; and this is something that may be found anywhere in maths and science textbooks. The learner has first to reach an understanding of a cluster of related concepts, all at the same time, and then immediately use this understanding in order to derive more concepts from the first ones. Note that these relationships are set up by means of a grammatical construction which faces both ways: '_a_ is defined as _x_', '_x_ is called _a_' -- both of which may occur in the same clause, as happens in the first sentence of the extract:

> '_a_ is defined as an _x_ which has feature _y_ which is called _b_'

Furthermore the 'hinge' element _y_ is itself fairly complex grammatically:

> with the special property that every point on it is at the same distance from a particular point

Thus while a technical term poses no great problem in itself -- there is nothing difficult about the word diameter, and its definition twice the radius is easy enough to understand provided you know what the radius is -- a technical construction of this kind, in which the terms interlock and are used to define each other, does present the learner with a considerable intellectual task. Writers sometimes try to make the task simpler by adding further definitions, not realizing that in a construct of this kind the greater the number of things defined the harder it becomes to understand.

(2) Technical taxonomies. These are related to the last heading; but the complexity is of a different kind. In the natural sciences, technical concepts have little value in themselves; they derive their meaning from being organized into taxonomies. Such taxonomies are not simply groups of related terms; they are highly ordered constructions in which every term has a definite functional value. As Wignell, Martin & Eggins point out in their study of the language of high school geography, a technical taxonomy is typically based on two fundamental semantic relationships: '_a_ is a kind of of _x_' (superordination) and '_b_ is a part of _y_' (composition). Thus in their example of _climate_, climate is divided into certain _kinds_ (Figure 2):

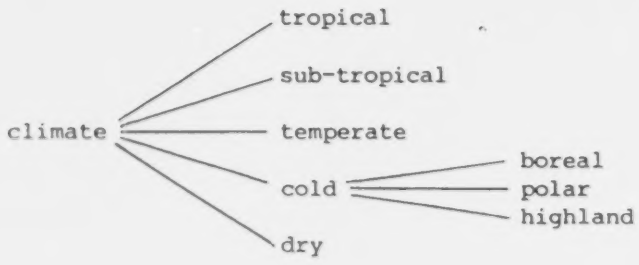

Figure 2. Kinds of climate (superordination)

and is composed of certain _parts_ (Figure 3):

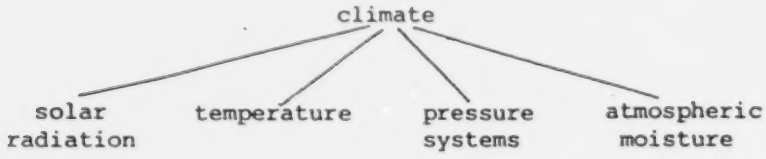

Figure 3. Parts of climate (composition)

It will be seen that the first is an 'either / or' relationship: 'every climate is _either_ tropical _or_ subtropical _or_ ...'; the second is a 'both + and' relationship: 'every climate is _both_ temperature _and_ solar radiation _and_ ...'. (We have to stretch the meaning of _either_ and _both_ here so that they are no longer limited to just two.)

Three problems can arise with such constructions. The first is that these taxonomies can become very complicated, with many layers of organization built into them. The second is that they are usually not made explicit; there are often neither lists nor diagrams (the figures above do

not appear in the textbook), so the student is left to work them out for himself from reading the text. The third problem is that the criteria on which these taxonomies are set up can also be extremely complex, so that they need to be described and explained in some detail.

It would be possible to make the reading matter more learner-friendly by dealing systematically with these three problems in turn: first introducing the terms in their taxonomic order (e.g. there are five kinds of climate, namely ...), then setting them out in lists or diagrams, and finally describing each category and, where possible, explaining it. In practice, the first and third steps are usually taken together, with the second one being left out; as a result, the way the taxonomy is presented is often grammatically very confusing, with no clear pattern of theme and information running through it. For example,

> ONE-CELLED ORGANISMS. Some organisms, such as the ameba and others in the culture you examined, are composed of only one cell. These organisms are said to be **unicellular.** Living in water, these animals are in close contact with the food, water, and oxygen they need. A one-celled animal takes in its own food. Along with this food, the animal also takes in some water. Additional water enters the animal cell by diffusion. The normal movement of the cytoplasm carries the food, water, and oxygen throughout the cell. Waste materials are eliminated directly to the outside of the cell. Most one-celled organisms can survive only in a watery environment.

It is very likely that the writer of this passage has been trying to make it more interesting for the reader by varying the order and the manner of presenting the categories to be learnt: the kinds of organism, the parts of the organism and so on. Thus every clause begins with a new theme: some organisms, these organisms, living in water, a one-celled animal, additional water, the normal movement of the cytoplasm, waste materials, most one-celled organisms. Unfortunately, while this kind of variation may be an admirable goal for a literary text, if scientific texts are written in this way they are much harder to read and to learn from. It is very difficult to construct the relevant taxonomies on the basis of this kind of writing.

(3) Special expressions. Some expressions used in mathematical language have a special grammar of their own, for example solving the open sentence over D. Here it is the expression as a whole that gets to be defined, rather than any particular word in it:

> If D is the domain of a variable in an open sentence, the process of finding the truth set is called solving the open sentence over D.

This is 'technical grammar', rather than technical terminology; it is not particularly problematic once it has been explained (provided the learner does not ask what happens if D is not the domain of a variable in an open sentence).

This kind of special grammar is more common in mathematics than in science; mathematicians have often had to stretch the grammar a little in order to say what they want. Already in Isaac Newton's writings we find some very long nominal constructions, like the following from the Treatise on Optics:

> The Excesses of the Sines of Refraction of several sorts of Rays above their common Sine of Incidence when the Refractions are made out of divers denser Mediums immediately into one and the same rarer Medium, suppose of Air, ...

-- all of which is merely the Subject of the clause. This kind of stretching of the grammar is less usual in scientific discourse. However, the language of science has brought its own innovations, stretching the grammar in ways which are at first sight less obvious but which, partly because they are less obvious, tend to cause greater difficulties of comprehension. Here is an example from an upper primary school textbook:

> Your completed table should tell you what happens to the risk of getting lung cancer as smoking increases.

The table is, of course, a table of figures; that is understood. But how does a table tell you something? -- tables do not talk, even tables of figures. And what kind of an object is a risk, such that we can ask what happens to it? And what does smoking increases mean: that more smoke is put out by some combustion process? What kind of relationship is being expressed by the as: does it mean 'while' (time), 'because' (cause), or 'in the same way that' (manner)?

What is being illustrated here is not, in fact, a single phenomenon. It is a set of interrelated phenomena: features which tend to go together in modern scientific writing, forming a kind of syndrome by which we recognize that something is written in the language of science. But although these features commonly go together, in order to understand the problems they pose to a student we will need to separate them out; and this will occupy the next three headings. The present section will serve as a

bridge leading into them, because when we see them in their historical perspective they do constitute a special mode of expression that evolved in scientific discourse, although we are now so used to them that we no longer think of them as special. It is only when they occur in a fairly extreme form that they stand out, as in the following (taken from an abstract):[3]

> [These results] are consistent with the selective perceptual orientation hypothesis if it is assumed that both word recognition and concurrent verbal memory produce more left than right hemisphere activation and that in the case of mixed lists in the present study this activation had not dissipated on form recognition trials.

(4) Lexical density. This is a measure of the density of information in any passage of text, according to how tightly the lexical items (content words) have been packed into the grammatical structure. It can be measured, in English, as the number of lexical words per clause.

In the following examples, each of which is one clause, the lexical words are underlined; the lexical density count is given at the right:

(a) But we never did anything very much in science at our school. 2

(b) My father used to tell me about a singer in his village. 4

(c) A parallelogram is a four-sided figure with its opposite sides parallel. 6

(d) The atomic nucleus absorbs and emits energy in quanta, or discrete units. 8

In any piece of discourse there is obviously a great deal of variation in the lexical density from one clause to the next. But there are also some general tendencies. In informal spoken language the lexical density tends to be low: about two lexical words per clause is quite typical. When the language is more planned and more formal, the lexical density is higher; and since writing is usually more planned than speech, written language tends to be somewhat denser than spoken language, often having around four to six lexical words per clause. But in scientific writing the lexical density may go considerably higher. Here are three clauses with a lexical density of 10 - 13, all from Scientific American:[4]

(e) Griffith's energy balance approach to strength and fracture also suggested the importance of surface chemistry in the mechanical behaviour of brittle materials. 13

(f) The conical space rendering of conical strings' gravitational properties applies only to straight strings. 10

(g) The model rests on the localized gravitational attraction exerted by rapidly oscillating and extremely massive closed loops of cosmic string. 13

When the lexical density goes up to this extent, the passage becomes difficult to read. Of course, the difficulty will also depend on the particular lexical items that are used and on how they are distributed in the grammatical structure; but the lexical desnity is a problematic factor in itself. In much scientific writing, almost all the lexical items in any clause occur inside just one or two nominal groups (noun phrases); compare examples (e) - (g) above, where this applies to all except one in each case (suggested, applies, rests). Perhaps the hardest examples to process are those which consist of strings of lexical words without any grammatical words in between, such as Griffith's energy balance approach, conical strings' gravitational properties; likewise those cited at the beginning of the paper, form recognition laterality patterns and glass crack growth rate. Even where the words themselves are perfectly simple and well known, as in the last of these four examples, the expressions are not easy to understand. Another example was the increasing lung cancer death rate, which appeared in the same passage as the example quoted in the last section. Here, however, another factor contributes to the difficulty, that of grammatical ambiguity; and this leads us in to our next heading.

(5) Syntactic ambiguity. Consider examples such as the following:

(h) Increased responsiveness may be reflected in feeding behaviour.

(j) Lung cancer death rates are clearly associated with increased smoking.

(k) Higher productivity means more supporting services.

All have a very simple structure: a nominal group, functioning as Subject, followed by a verbal group, followed by another nominal group with (in two instances) a preposition introducing it. If we focus attention on the verbal expressions, may be reflected (in), are ... associated (with), means, we find that they are ambiguous; and they are ambiguous in two respects. In the first place, we cannot tell whether they indicate a relationship of cause or of evidence. Is one thing being said to be the effect of another,

or is it merely the outward sign of it? For example: in (h), does the feeding behaviour demonstrate that responsiveness has increased, or does it change as a result of the increase? In the second place, supposing that we can identify a relationship of cause, we still cannot tell which causes which. In (k), for example, is higher productivity brought about by more supporting services, or does it cause more supporting services to be provided? It may seem obvious to the writer, and also to a teacher, which meaning is intended; but it is far from obvious to a learner, and teacher and learner may interpret the passage differently without either of them being aware that another interpretation was possible.

The expression are associated with, in (j), can also face in either direction: either 'cause' or 'are caused by'. We may know that smoking causes cancer, and hence that the more you smoke, the more likely you are to die from cancer of the lung. But this sentence could mean that lung cancer death rates lead to increased smoking: perhaps people are so upset by fear of lung cancer that they need to smoke more in order to calm their nerves. It is even possible that the writer wanted not to commit himself to a choice between these two interpretations of the statistics. But when we start to explore the meaning of this example more carefully, we find that it contains a great deal more ambiguity in addition to that which we have already seen in the verb.

For example, what does lung cancer death rates mean? Is it 'how many people die from lung cancer', or 'how quickly people die when they get lung cancer'? Or is it perhaps 'how quickly people's lungs die from cancer'? And does increased smoking mean 'people smoke more', or 'more people smoke' -- or is it a combination of the two, 'more people smoke more'? Having reached some understanding up to this point, such as 'more people smoke ... more people die of cancer', we still do not know whether they are the same people or not -- is it just the smokers who die more, or everyone else as well? Nor do we know whether the situation is real or hypothetical: is it 'because more people are smoking, so more are dying', or 'if more people smoked, more would die'? If we combine all these possibilities we have already reached some fifty possible interpretations, most of which were quite plausible; they are genuine alternatives faced by a human reader, not fanciful simulations of some computerized parsing program.

Where does this ambiguity come from? It arises from various sources. We have already referred to polysemous verbs like mean, be associated with; there are probably between one and two thousand verbs of this class in use in scientific English. But the main cause of ambiguity is that clauses are turned into nouns. That is to say, something that would in spoken English be

typically expressed as a clause is expressed instead as a group of words centring on a noun. If I say Mary announced that she had accepted, I am making it clear who did what; but if I say the announcement of Mary's acceptance, you cannot tell (i) whether Mary made the announcement herself or someone else did, (ii) whether Mary was accepting (something) or being accepted, (iii) whether she had accepted / been accepted already or would accept / be accepted in the future. Thus the single nominal group the announcement of Mary's acceptance corresponds to many different wordings in the form of a clause: Mary announced that she would accept, they announced that Mary had been accepted, and so on. A great deal of semantic information is lost when clausal expressions are replaced by nominal ones.

Scientific writing uses very many nominal constructions of this kind, typically in combination with verbs of the type illustrated in (h) - (k) above. Both these features are, as we have seen, highly ambiguous, although we usually do not recognize the ambiguity until we try to re-word the passage in some other form. Here is a further example:

(l) The growth of attachment between infant and mother signals the first step in the development of the child's capacity to discriminate amongst people.

Possible rewordings of this might be:

{When / If} an infant and {its / a} mother {start to grow / grow more} attached to one another, {this shows that / this is because} the child {is taking / has taken} the first steps towards {becoming / becoming more} capable of {distinguishing / preferring} one person from/to another.

Combining these we get $2^7 = 128$ possible interpretations. But in this instance I find it difficult to opt for any one of them; none of the rewordings seems to be particularly convincing.

(6) Grammatical metaphor. The high lexical density and the ambiguity discussed in the last two sections are both by-products of a process I shall refer to as 'grammatical metaphor'. This is like metaphor in the usual sense except that, instead of being a substitution of one word for another, as when we say you're talking tripe instead of you're talking nonsense, it is a substitution of one grammatical class, or one grammatical structure, by

another; for example, his departure instead of he departed. Here the words (lexical items) are the same; what has changed is their place in the grammar. Instead of pronoun he + verb departed, functioning as Actor plus Process in a clause, we have determiner his + noun departure, functioning as Deictic plus Thing in a nominal group.[5] Other examples are her recent speech concerned poverty instead of she spoke recently concerning poverty; glass crack growth rate instead of how quickly cracks in glass grow. Often the words may change as well as the grammar, as in the last example where how quickly is replaced by rate -- we do not usually say glass crack growth quickness; but the underlying metaphor is in the grammar, and the lexical changes follow more or less automatically.

I am not suggesting that there will always be some absolute, non-metaphorical form to which these grammatical metaphors can be related; metaphor is a natural historical process in language and modes of expression involving different degrees of metaphor will always exist side by side. We can often take two or three or even more steps in rewording a grammatical metaphor in a less metaphorical, more congruent form; for example, we might say that 'cracking' is really a process -- something happening -- rather than a thing, so that cracks in glass, with cracks as a noun, is a metaphor for glass cracks with cracks as verb. As another example,

(m) [The 36 class only appeared on this train] in times of reduced loading, or engine failure.

could be reworded as when loadings were reduced, or the engine failed; but we might then reword the first part over again as when the load was smaller or even when fewer goods were being carried.

What is the nature of this rewording? One way of thinking of it is by imagining the age of the reader, or listener. In talking to a nine-year-old, we would never say in times of engine failure; we would say whenever the engine failed. Notice that we have not had to simplify the vocabulary; there are no difficult words in the first version -- it is the grammar that is difficult for a child. Similarly we would change slow down the glass crack growth rate to make the cracks in glass grow more slowly, or stop the cracks in glass from growing so quickly. What we are doing, when we reword in this way, is changing the grammar (with some consequential changes in vocabulary) by making it younger. Children learn first to talk in clauses; it is only later -- and only when they can already read and write with facility -- that they are able to replace these clauses with nominal groups.

As far as we can tell, this also reflects what happened in the history of the language. In English, and other languages of Europe, the older pattern is the clausal one; and it is based on certain principles of wording which we might summarize as follows:

(1) processes (actions, events, mental processes, relations) are expressed by verbs;

(2) participants (people, animals, concrete and abstract objects that take part in processes) are expressed by nouns;

(3) circumstances (time, place, manner, cause, condition) are expressed by adverbs and by prepositional phrases;

(4) relations between one process and another are expressed by conjunctions.

For example:

participant	process	circumstance	relation between processes	participant	process	circumstance
the cast	acted	brilliantly	so	the audience	applauded	for a long time
[noun]	[verb]	[adverb]	[conjunction]	[noun]	[verb]	[prepositional phrase]

If this is now reworded metaphorically as:

the cast's brilliant acting	drew	lengthy applause	from the audience
[noun]	[verb]	[noun]	[prepositional phrase]

a number of changes have taken place. The processes acted and applauded have been turned into nouns, acting and applause; the participant the cast has become a possessive, while the audience has become part of a prepositional phrase. The circumstances brilliantly and for a long time have both become adjectives inside nominal groups; and the relation between the two processes, showing that one of them caused the other, has become a verb, drew. This makes it sound as though acting and clapping were things, and as if the only event that took place was the causal relation between them (... acting drew ... applause). All these changes illustrate what is meant by grammatical metaphor.

This kind of metaphor is found particularly in scientific discourse, and may have evolved first of all in that context. It is already beginning to appear in the writings of the ancient Greek scientists; from them it is carried over into classical Latin and then into medieval Latin; and it has continued to develop -- but to a far greater extent -- in Italian, English, French, German, Russian and the other languages of Europe from the Renaissance onwards. And although it has spread across many different registers, or functional varieties, of language, in English at least the main impetus for it

seems to have continued to come from the languages of science.

Why did scientific writers, from Isaac Newton onwards, increasingly favour such a mode of expression? -- one in which, instead of writing 'this happened, so that happened', they write 'this event caused that event'? These were not arbitrary or random changes. The reason lies in the nature of scientific discourse. Newton and his successors were creating a new variety of English for a new kind of knowledge; a kind of knowledge in which experiments were carried out; general principles derived by reasoning from these experiments, with the aid of mathematics; and these principles in turn tested by further experiments. The discourse had to proceed step by step, with a constant movement from 'this is what we have established so far' to 'this is what follows from it next'; and each of these two parts, both the 'taken for granted' part and the new information, had to be presented in a way that would make its status in the argument clear. The most effective way to do this, in English grammar, is to construct the whole step as a single clause, with the two parts turned into nouns, one at the beginning and one at the end, and a verb in between saying how the second follows from the first.

I have written about the history of this development elsewhere, with illustrations from some of the earlier texts.[6] What I am presenting here is a very simplified account; there are, obviously, countless variations on the pattern described above. Nevertheless these variants all derive from the basic principle of organizing information into a coherent form that suited the kind of argumentation that came to be accepted as 'scientific'. Here is a contemporary example, taken from the Scientific American:

> The atomic nucleus absorbs and emits energy only in quanta, or discrete units. Each absorption marks its transition to a state of higher energy, and each emission marks its transition to a state of lower energy.

Notice how, in the second sentence, each clause consists of (i) a 'taken for granted' part, nominalizing what has been said before (the atomic nucleus absorbs energy → each absorption; the atomic nucleus emits energy → each emission); (ii) a 'new information' part, pointing forward to what is to come, and also nominalized (its transition to a state of higher / lower energy); and (iii) the relation between them, in the form of a verb (marks). Frequently the 'taken for granted' part summarizes the whole of a long previous discussion; for example, the same article contains the sentence:

> The theoretical program of devising models of atomic nuclei has of course been complemented by experimental investigations.

This has exactly the same pattern; but here the 'taken for granted' part (the theoretical program ... atomic nuclei) is referring back to many paragraphs of preceding text.

If we reword these so as to take the metaphor out, the entire balance of the information is lost. For the last example we might write:

> We devised models of atomic nuclei, in a program of theoretical [research], and in addition of course we investigated [the matter] by doing experiments.

But this would give us no indication that the first part was a summary of what had gone before, or that the last part was going to be taken up and developed in what followed. What is equally important, it would fail to make it clear that each step -- devising theoretical models and investigating experimentally -- is to be understood as a unity, a single phenomenon rather than an assembly of component parts.

It would be wrong to give the impression that in developing this favourite type of clause structure, and the grammatical metaphor that made it possible, the scientists were guided by any conscious planning. They were not. Newton and his contemporaries did discuss the best ways of constructing a scientific paper, and they tried to regulate the use of vocabulary for building elaborate taxonomies, especially in biology (and taken up later on in chemistry); but they were not aware of their own use of grammar, and these forms evolved naturally in response to pressure from the discourse.[7] It is only when we analyse this discourse grammatically, using a functional grammar, that we can appreciate how the patterns relate to what the scientists were trying to achieve.

I have not presented the detailed grammatical analysis here; it would need too much space. But it is helpful, I think, to bring out the nature of grammatical metaphor, and the sense in which these forms can be said to be metaphorical, because almost every sentence in scientific writing will contain some example of it, and it does present problems to the learner. This is partly a que stion of maturity: students well into secondary school may still find it difficult to comprehend, even if they have been educated throughout in English medium.[8] For those who are taking up English just as a language for science and technology, the problem may be greater or less depending on the degree and kind of grammatical metaphor found in the language(s) they have used as medium of education before.

It seems likely that part of the difficulty arises, however, because these metaphorical expressions are not just another way of saying the same thing. In a certain sense, they present a different view of the world. As we grew up, using our language to learn with and to think with, we have come to expect (unconsciously, until our teachers started to give us lessons in grammar) that nouns were for people and things, verbs for actions and events. Now we find that almost everything has been turned into a noun. We have to reconstruct our mental image of the world so that it becomes a world made out of things, rather than the world of happening -- events with things taking part in them -- that we were accustomed to. Some of the problem may even be ideological: the student may want to resist this view of reality that he feels is being imposed on him by the language of science. It is worth noting, in this connection, that the scientists themselves are now becoming dissatisfied with the language they use in their writings. They too feel that it has gone too far in this direction, and that if they are to continue to develop new ideas in science they will need to return to less nominalized forms of expression.[9]

(7) Semantic discontinuity. This is my final heading; I am using it to point out that writers sometimes make semantic leaps, across which the reader is expected to follow them in order to reach a required conclusion. Let me discuss just one example:

> In the years since 1850, more and more factories were built in northern England. The soot from the factory smokestacks gradually blackened the light-coloured stones and tree trunks.
>
> Scientists continued to study the pepper moth during this time. They noticed the dark-coloured moth was becoming more common. By 1950, the dark moths were much more common than the light-coloured ones.
>
> However, strong anti-pollution laws over the last twenty years have resulted in cleaner factories, cleaner countryside and an increase in the number of light-coloured pepper moths.

The first two paragraphs are rather straightforward; but in the third paragraph, problems arise. Taken as a whole, it is a typical example of the structure described in the last section: two processes, with a logical connection between them. The sense is '<u>a</u> happened, so <u>x</u> happened', expressed metaphorically in the form of 'happening <u>a</u> caused happening <u>x</u>' (<u>strong anti-pollution laws ... have resulted in cleaner factories ...</u>). We might reword this part as:

> Over the last twenty years, [the government have passed] strong laws to stop [people] polluting; so the factories [have become] cleaner ...

We saw above that the main reason for choosing the metaphorical form was that 'happening a' was something that had been presented before, and so here was being referred to as a whole, as a kind of package or summary of what was to be taken for granted and used as a point of departure for the next step in the argument. However, in this instance happening a has not been presented before; this is the first time we have heard of any 'anti-pollution laws'. So the reader has to (i) discover that it is new information, (ii) decode it and (iii) use it as a stepping-off point for understanding something else.

But let us suppose that the reader has coped with this difficult assignment. He now comes to 'happening x' and finds that this is a co-ordination of three processes, all of them presented metaphorically: cleaner factories, cleaner countryside and an increase in the number of light-coloured pepper moths. Rewording this, he begins to understand:

> ... the factories have become cleaner, the countryside has become cleaner, and there are more light-coloured pepper moths than before.

-- that is, the moths have also become cleaner: only a few of them are now affected by dirt in the air. But that is not at all the intended message. What the reader is supposed to do is to insert another logical relationship between each pair of these resulting processes, and then draw a highly complex conclusion from them:

> ... the factories have become cleaner, [so] the countryside has become cleaner, and [so] there are getting to be more of the light coloured pepper moths [because they don't show up against clean trees, and therefore do not get eaten by the birds as much as they did when the trees were dirty].

In other words, the learner is expected to work out for himself the principle of natural selection.

This is a particularly problematic example. The language is highly metaphorical, in the sense of grammatical metaphor; the first part of the sentence is misleading because it suggests that we know about the 'strong anti-pollution laws' already, and in the second part the reader is required to perfom two complicated semantic leaps -- inserting the two causal connectives, and working out the implications of the second one.

But it is not uncommon to find semantic discontinuities of one kind or another in scientific writing; the specialist has no trouble with them -- but for learners they are an additional hazard. Of all the kinds of difficulty discussed in these few pages, this is the one a teacher can do least towards helping students to solve. The teacher can give a few illustrations, and warn the students to be on their guard; but every instance seems to be unique, and it is hard to find any general principles behind them all.

* * * * * * *

Most of the features described under these seven headings could in prinoiple occur independently of each other. But they are all closely related, and, excepting perhaps those mentioned under (3), 'special expressions' (in mathematics), they tend to cluster together as characteristics of scientific discourse. I have tried to show that they are not arbitrary -- that they evolved to meet the needs of scientific method, and of scientific argument and theory. They suit the expert; and by the same token they cause difficulty to the novice. In that respect, learning science is the same thing as learning the language of science. Students have to master these difficulties; but in doing so they are also mastering scientific concepts and principles.

At the same time, it must be said that many of those who write in the language of science write it very badly. They leave implicit things that need to be made explicit, create multiple ambiguities that cannot readily be resolved, and use grammatical metaphor both inappropriately and to excess. The language thus becomes a form of ritual, a way of claiming status and turning science into the prerogative of an elite. Learners who complain that their science texts are unnecessarily difficult to read may sometimes be entirely justified. And we are all familiar with those who, not being scientists, have borrowed the trappings of scientific language and are using it purely as a language of prestige and power -- the bureaucracies and technocracies of governments and multinational corporations.[10] In bureaucratic discourse these features have no reason to be there at all, because there is no complex conceptual structure or thread of logical argument. But they serve to create distance between writer and reader, to depersonalize the discourse and give it a spurious air of being rational and objective.

In my view the best tool we have for facing up to this kind of language, criticizing it where necessary but above all helping students to understand it, is a functional model of grammar. This enables us to analyse any passage and relate it to its context in the discourse, and also to the general background of the text: who it is written for, what is its angle on the subject matter, and so on. Grammatical analysis is a fairly technical exercise, and not something that students can be expected to undertake for themselves unless they are specializing in language. But science teachers (provided they can be persuaded to discard traditional prejudices about grammar!) may find it interesting and rewarding to explore the language of their own disciplines; and also, where this applies, to compare scientific English with scientific registers that have evolved, or are now evolving, in the major languages of the region in which they work.

NOTES

[1] See entries in the Bibliography for Taylor (1979), Martin & Rothery (1986), Wignell, Martin & Eggins (1987), Ravelli (1985). Primary texts for the historical survey were Geoffrey Chaucer, A Treatise on the Astrolabe (1391); Isaac Newton, Optics (1704): Joseph Priestley, The History and Present State of Electricity (1767); John Dalton, A New System of Chemical Philosophy (1827); Charles Darwin, The Origin of Species (1859); James Clerk Maxwell, An Elementary Treatise on Electricity (1881). Texts from the Scientific American were Hamilton & Maruhn, 'Exotic atomic nuclei' (July 1986); Michalske & Bunker, 'The fracturing of glass', Vilenkin, 'Cosmic strings' (Dec. 1987). For the University of Birmingham studies see King (in press). A sketch of some features of the grammar of scientific English is contained in Halliday (1988); the work from which the present paper is mainly derived was presented in lecture form in Halliday (1986).

[2] Sources for the upper primary / lower secondary science and mathematics texts quoted in this paper are A. McMullen & J.L. Williams, On Course Mathematics (Macmillan Australia, 1971); Intermediate Science Curriculum Study, Well-being: probing the natural world (Martin Educational, 1976); A.A. Parkes, K.E. Couchman & S.B. Jones, Betty and Jim: year six mathematics (Shakespeare Head Press, 1978); R.L. Vickery, J.H. Lake, L.N. McKenna & A.S. Ryan, The Process Way to Science (Jacaranda Press, 1978). The taxonomies of climate are from Colin Sale, Graeme Wilson & Ben Friedman, Our Changing World (Longman Cheshire, 1980), quoted in Martin, Wignell, Eggins & Rothery (1988).

[3] From the Abstract to Joseph B. Hellige, 'Visual laterality patterns for pure- versus mixed-list presentation' (Journal of Experimental Psychology 4.1, 1978).

[4] December 1987, pp. 80, 58, 58.

[5] For the analysis of the grammar see Halliday (1985), Chapters 5 and 6.

[6] See Halliday (1988).

[7] For the evolution of the scientific article see Bazerman (1988). For an account of the work of the scientific language planners at the time of Newton, see Salmon (1966, 1979).

[8] See Lemke (1982, 1983) for the results of a detailed investigation of the teaching of science in American high schools. For discussion of science education in Britain, with reference to the language of science, see White (198).

[9] This point is discussed briefly in Halliday (1987).

[10] For a study of the language of written communication within a government department see Hardaker (1982). For an analysis of the nature and function of technocratic discourse see Lemke (in press).

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